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16. Abstract <p>Screening tests using three commercial coatings (Jocoat, HI-15, and RT-1A) on the nickel-base alloy NASA WAZ-20 were performed by cyclic exposure in a Mach 1 burner facility. These tests showed Jocoated WAZ-20 to have the best cracking resistance. The thermal fatigue resistance of Jocoated WAZ-20 in both the random polycrystalline and directionally solidified polycrystalline forms relative to that of other superalloys was then evaluated in a fluidized-bed facility. This investigation showed that Jocoated random polycrystalline WAZ-20 ranked approximately in midrange in thermal fatigue life. The thermal fatigue life of directionally solidified Jocoated WAZ-20 was shorter than that of other directionally solidified alloys but still longer than that of all alloys in the random polycrystalline form.</p>					
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THERMAL FATIGUE RESISTANCE OF NASA WAZ-20 ALLOY WITH THREE COMMERCIAL COATINGS

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SUMMARY

WAZ-20, a nickel-base alloy developed at the Lewis Research Center, has potential, because of its high strength, for high-temperature applications where good thermal fatigue resistance would be required. For an elevated-temperature application, surface protection would be needed to prevent excessive oxidation. Therefore, an investigation was conducted to determine the thermal fatigue resistance of coated WAZ-20 alloy relative to that of other superalloys.

In addition to a metallurgical investigation, this study consisted of two sets of cyclic tests - both conducted between metal temperatures of 1065° C and 340° C. First, screening tests using three commercial coatings (Jocoat, HI-15, and RT-1A) applied to WAZ-20 were performed in a Mach 1 natural-gas burner facility. Vendors applied coatings which they selected as potentially suitable for the WAZ-20 alloy. Jocoated WAZ-20 exhibited the best thermal cracking resistance. Next, Jocoat was applied to other WAZ-20 specimens for testing in a fluidized-bed facility. Relative thermal fatigue resistance was determined for Jocoated wedges cast in both the random polycrystalline and directionally solidified polycrystalline forms. Jocoated random polycrystalline WAZ-20 ranked approximately in midrange of the thermal fatigue lives previously obtained with most known nickel- and cobalt-base alloys. Its life was longer than that of Jocoated MarM 200 alloy, about equal to those of NASA VI-A and René 80 alloys, but shorter than that obtained for Jocoated IN 100 alloy. The directionally solidified polycrystalline form of Jocoated WAZ-20 had a thermal fatigue life about 14 times longer than that of the coated random polycrystalline form but ranked lower in life compared to the two other coated directionally solidified alloys (NX 188 and IN 100) for which data were available.

INTRODUCTION

The NASA WAZ-20 nickel-base alloy has potential for application to turbine engine components in which thermal fatigue cracking would probably be the dominant failure mode. One such application would be the stator vanes of advanced gas turbine engines (ref. 1). For such an elevated-temperature application, surface protection would be required to prevent excessive oxidation. The relative thermal fatigue resistance of coated WAZ-20 would, therefore, be of interest to potential users.

This investigation was conducted to determine the thermal fatigue resistance of coated WAZ-20 relative to that of other superalloys. The thermal fatigue resistance of coated WAZ-20 would necessarily have to be evaluated below its expected use temperature to obtain a relative comparison with existing data for other superalloys (ref. 2). However, a favorable comparison would show that the high-temperature properties of WAZ-20 would not have to be sacrificed to obtain good lower temperature thermal fatigue properties. This study was made in two parts. First, screening tests using three commercial coatings applied to WAZ-20 were performed by cyclic exposure in a burner facility. Second, the coating on WAZ-20 with the best resistance to thermal fatigue cracking in these screening tests was applied to other wedge-shaped WAZ-20 specimens. These specimens were then tested in a fluidized bed to determine their thermal fatigue resistance relative to that of other specimens.

For the first part of the study (burner tests), each of three commercial coatings was applied to as-cast random polycrystalline wedges of WAZ-20. Three different vendors applied the coatings which they selected from their inventory as potentially suitable for the WAZ-20 alloy. These coatings were Jocoat, HI-15, and RT-1A. Jocoat is a silicon-modified nickel aluminide coating. HI-15 is a chromium-modified nickel aluminide coating. RT-1A is a chromium-aluminum duplex coating. Each of the coatings has provided oxidation and/or thermal fatigue resistance for a number of nickel-base superalloys in the 980° to 1100° C maximum temperature range (refs. 2 and 3). In the screening tests, these coated WAZ-20 systems were exposed in a Mach 1 natural-gas stream for 3 minutes, which gave a maximum metal temperature of 1065° C, followed by an air quench for 30 seconds, which gave a minimum metal temperature of 340° C for each test cycle. From data taken at various inspection times, macrocrack initiation and propagation and specimen weight change were determined. Microhardness surveys and a metallographic study were also made in an attempt to relate coating properties to thermal fatigue cracking resistance.

In the second part of this study (fluidized-bed tests), Jocoat was applied to WAZ-20 wedges cast in both the random and directional polycrystalline forms. The metal test temperatures and cyclic times to which specimens were subjected were the same as in the screening study except that the cycle time to the minimum metal temperature

(340° C) was 3 minutes, as opposed to 30 seconds for the screening study. The thermal fatigue resistance of coated WAZ-20 in each of the polycrystalline forms was compared with that of identically exposed specimens made from a wide range of nickel- and cobalt-base alloys, some of which were also coated and/or directionally solidified. A metallurgical study of the coated WAZ-20 bars after fluidized-bed testing was also conducted.

The work was conducted in the U.S. customary system of units. Conversion to the International System of Units (SI) was made for reporting purposes only.

MATERIALS AND EXPERIMENTAL PROCEDURE

Alloy

The alloy used in this investigation was the nickel-base alloy designated WAZ-20, which was developed at the Lewis Research Center (ref. 1). The nominal composition in weight percent is 17 to 20 percent tungsten, 6 to 7 percent aluminum, 1.4 to 1.6 percent zirconium, 0.10 to 0.20 percent carbon, and the balance nickel. WAZ-20 has an incipient melting point of about 1300° C. It has an ultimate tensile strength of 138 MN/m² at 1205° C, which is greater than that for any known cast nickel-base alloy.

Remelt stock of WAZ-20 was prepared by induction melting the correct proportions of the various alloying elements. This was done under an inert gas (commercially pure argon) cover in stabilized zirconia crucibles. The exposure time between melt and crucible was approximately 20 minutes. The melt was superheated to 1650° C and poured at 1590° C into zircon shell molds preheated to 870° C to make the 5-cm-diameter by 5-cm-high cylindrical pigs. As shown in table I, the wet chemical analysis of the remelt stock showed the composition to be within the range of the specified nominal composition of WAZ-20 alloy.

Test Specimens

The test specimens were cast under vacuum to the dimensions shown in figure 1 from a remelt of the pigs. A pressure of 10⁻³ torr or less was maintained during melting and pouring. Pour temperature after a superheat to approximately 1650° C was 1565° ± 15° C for both the random and directionally solidified polycrystalline specimens. The melt was poured into zircon shell molds which were preheated to 870° C to obtain the random polycrystalline test specimens. The directionally solidified test specimens were also made in zircon shell molds by a controlled solidification process, as detailed in reference 4.

The as-cast specimens were vapor blasted. Visual, X-ray, and fluorescent-dye

penetrant inspections were performed on all specimens before testing. Single-wedge specimens, as shown in figure 1(a), were cast only in the random polycrystalline form for the burner tests. Double-wedge specimens, as shown in figure 1(b), were cast in both the random polycrystalline and directionally solidified polycrystalline forms for the fluidized-bed tests.

Coatings

Three commercial coatings were applied by vendors to single-wedge specimens (fig. 1(a)) of WAZ-20 alloy. Initially, each coating was applied to two as-cast random polycrystalline wedges. The coatings investigated were designated by their vendors as Jocoat, HI-15, and RT-1A. Jocoat is a silicon-modified nickel aluminide coating which was applied by TRW, Inc. It was applied under license from Pratt & Whitney Aircraft in accordance with specification PWA 47. HI-15 is a chromium-modified nickel aluminide coating applied by Alloy Surfaces. Approximately 9 mg/cm^2 was applied, resulting in a case depth of about $75 \text{ }\mu\text{m}$. RT-1A is a chromium-aluminum duplex coating applied by a proprietary process of Chromalloy American Corporation. After the results of the coating screening study were obtained, the coating exhibiting the best thermal cracking resistance in combination with the WAZ-20 alloy was then applied by the original vendor to double-wedge specimens (fig. 1(b)) of WAZ-20 alloy for fluidized-bed testing.

Test Facilities and Procedures

Burner. - Figure 2(a) shows a general view of the Mach 1 burner facility used for the screening portion of this investigation. Burners of this type, which are described in detail in reference 5, have been used at Lewis to study oxidation, erosion, and corrosion of superalloys. The burner was fueled with natural gas and operated at a mass flow of 0.5 kg/sec at 1650°C to obtain a maximum specimen temperature of 1065°C , which occurred after 3 minutes of heating. The six test and two control specimens were tested simultaneously by using the rotating specimen holder shown in figure 2(b). This holder was moved vertically between heating and cooling positions by an air cylinder. In the heating position the specimens were partially surrounded by a clamshell shield to minimize radiation losses. A slip ring assembly, mounted in the lower end of the specimen holder shaft, was used to provide an electric circuit to thermocouples mounted in the two control specimens.

The specimens were alternately heated for 3 minutes to obtain a maximum temperature of 1065°C and cooled for 30 seconds to obtain a minimum temperature of 340°C . Prior to testing, all specimens were visually inspected along the leading edge by using

a microscope with a magnification of x40 and were then weighed on an analytical balance to within ± 0.1 mg. Subsequently, after 25, 50, 100, 182, 300, and 494 cycles the specimens were removed from the holder, reweighed, photographed, and again inspected for cracks. When cracks were observed, the location and length on each side was measured and recorded. The crack information is presented on an area basis in order to make it somewhat independent of the geometry. Crack area was calculated from the measurements on each side of the specimen by assuming the crack front to be a straight line. The number of cycles to crack initiation was taken as the average of the number of cycles at the last inspection to show no cracking plus the number of cycles at the first inspection to show cracking. After 182 cycles, one each of the HI-15 and RT-1A coated specimens were removed for metallurgical examination and replaced by a dummy specimen.

Fluidized bed. - Figure 3(a) is a schematic view of the fluidized-bed test facility used to evaluate the relative thermal fatigue resistance of superalloys. This facility, described in detail in reference 6, was designed, built, and operated by the IIT Research Institute under contract to NASA Lewis Research Center. Both the hot and cold beds consist of a retort filled with 300- to 540- μ m alumina through which air is pumped. Adjustment of the airflow allows the sand particles to develop a churning, circulating action - hence, the name "fluidized." The large mass of the beds and their "fluid" action promote uniform, high heat-transfer rates. Eighteen specimens were tested simultaneously in the holder shown in figure 3(b). Duplicate specimens of coated WAZ-20 in both the random polycrystalline and directionally solidified polycrystalline forms were cycled. The specimens were cycled between beds by means of an automatically controlled, pneumatic-cylinder-operated, transfer mechanism.

In this facility each bed is maintained at constant temperature. Calibration tests were performed to determine the correlation of metal temperatures with bed temperatures for the cyclic times used in this program. The specimens were alternately heated for 3 minutes in a 1090 $^{\circ}$ C bed (maximum WAZ-20 metal temperature obtained, 1065 $^{\circ}$ C) and cooled for 3 minutes in a 315 $^{\circ}$ C bed (minimum WAZ-20 metal temperature obtained, 340 $^{\circ}$ C). Hence, the maximum and minimum specimen metal temperatures were identical to those obtained in the screening tests. The calibration results also revealed that the maximum temperature gradient within these test specimens occurred about 9 seconds after start of heating and was approximately 370 $^{\circ}$ C. Prior to testing, all specimens were visually inspected along the leading edge by using a microscope with a magnification of x30. Subsequently, after approximately 25, 50, 100, 200, 300, 500, 750, 1000, 1500, and at least every 750 cycles thereafter, the specimens were again inspected for cracks. The number of cycles to crack initiation was calculated in the same manner as for the burner test (average of the number of cycles at the two inspections between which cracking occurred).

Metallographic Procedure

After completion of both the screening study and the thermal fatigue study, samples were sectioned for metallographic study. Data for all the photomicrographs shown in the figures are described in table II. For the longitudinal sections a portion of the test bar containing a major crack was cut and mounted in epoxy. Transverse sections of the test bar were mounted in thermosetting plastic. In the screening study, transverse sections were taken at the hottest spanwise position, which was about 70 mm above the base of the specimen (33 mm above the heat shield). Transverse sections from the screening study designated "unexposed" were removed from a location 25 mm below the top of the heat shield because this area was not exposed to the gas stream. As this area was also air cooled during testing, this location was not even heat tinged after 494 cycles and would, therefore, be typical of "as coated" material. Samples were prepared according to conventional metallographic practice. The reagent used for the etched samples was 33 parts nitric acid, 33 parts acetic acid, 1 part hydrofluoric acid, and 33 parts water.

Microhardness and Coating Thickness Measurements

After completion of the screening tests, microhardness measurements were made at each of four positions on transverse metallurgical sections of the coated bars. These positions were in the coating outer layer, in the coating inner layer, at the interface between coating and substrate, and at the centerline of the substrate. Several measurements were made at each position by using a Knoop indenter with a 50-gram load. The average Knoop hardness numbers (KHN) at the four positions of the hot test section after 494 cycles of testing were compared with those obtained from the unexposed section near the base of the test specimen. Average thicknesses of the coating outer layer, the coating inner layer, and the interface layer between the coating and substrate are also presented for both the hot and unexposed sections.

RESULTS AND DISCUSSION

The results of this investigation are presented in two parts. First, the results of the burner test screening study of three commercial coatings on NASA WAZ-20 alloy are presented. Second, the fluidized-bed thermal fatigue resistance of coated WAZ-20 relative to that of other superalloys is described. For both studies, the specimens were cycled between the same maximum (1065°C) and minimum (340°C) metal temperatures.

Burner Test Screening Study

Macrocrack initiation and propagation. - Macrocrack data for the coated specimens of WAZ-20 alloy tested in the Mach 1 burner facility are presented in figure 4. This figure shows the cycles to crack initiation as well as the change in crack area with the number of cycles (to 494 cycles). Figure 4(a) shows that the Jocoated specimens were best, with no leading-edge cracks at the 100-cycle inspection but with one crack in each specimen at the 182-cycle inspection. Figures 4(b) and (c) show that both HI-15 and both RT-1A coated specimens, respectively, had cracked at the leading edge before the first inspection (25 cycles). Each specimen had one crack, except for one of the HI-15 coated specimens which had two cracks. The number of cycles to macrocrack initiation as described in the test procedure was taken as the average of the number of cycles at the last inspection to show no cracking plus the number of cycles at the first inspection to show cracking. This procedure results in a cyclic life for RT-1A coated and HI-15 coated WAZ-20 of about 13 cycles and for Jocoated WAZ-20 of about 141 cycles. Hence, the Jocoated specimens had a cyclic life to first crack about 10 times that of the RT-1A coated and HI-15 coated specimens. It is concluded that the type of coating significantly affected the initiation of substrate cracking. The mechanism by which this appears to occur is discussed in the section Metallography and microhardness.

The first crack in each specimen occurred on the thin leading edge because the thermal stress on this edge is higher than on the thicker back edge. However, after cracks had propagated a certain distance at the leading edge, the thermal stresses along the leading edge would be reduced and cracks would then initiate and propagate from the back edge. This interaction of cracks on the two edges (in addition to multiple crack initiation on either edge) means that crack propagation data are probably of limited use beyond the point where back-edge cracking occurs. For this reason, detailed crack propagation data were obtained only at the leading edge. Initiation of back-edge cracking, however, may be related to the cracking resistance of each coating type. Thus, back-edge cracks were first observed at the 100- and 182-cycle inspection for the two HI-15 coated bars, the average initiation being at 108 cycles. Both RT-1A coated and Jocoated specimens had back-edge cracks at the 182- and 494-cycle inspections, the average crack initiation being 141 and 397 cycles, respectively. The approximate number of cycles to initiation of back-edge cracking (fig. 4) tends to confirm that crack growth rate is arrested when back-edge cracking begins. Based upon cycles to initiation of back-edge cracking alone, Jocoat would appear to be most crack resistant, followed by RT-1A and HI-15. From these data, it is seen that initiation of the first macrocrack was reproducible for each coating. However, the observed crack growth rates (fig. 4) were not reproducible with any one coating and varied considerably among the coatings. On the basis of crack initiation, WAZ-20 coated with Jocoat was selected to evaluate its thermal fatigue resistance relative to that of conventional superalloys.

Weight change. - Weight change data for the coated specimens of WAZ-20 alloy tested in the Mach 1 burner facility are presented in figure 5. Initially, the Jocoated specimens showed a very large weight gain followed by a continuous lower rate weight gain for the duration of testing. The RT-1A coated specimens showed a continuous weight loss during all cycling. The HI-15 coated specimens had a small initial weight gain and then a lower rate of weight gain for the duration of testing.

The crack oxidation can be observed by referring to figure 6, which shows the two sides of one of each type of coated specimen after testing to 494 cycles. In order to illustrate the surface appearance and cracks in the photographs, oblique illumination was used to enhance these characteristics. Figure 6(a) shows that the HI-15 coated WAZ-20 specimen had large eruptions at the crack locations, with the remainder of the specimen being fairly smooth. The small weight gain noted for these specimens was mostly due to the oxidation buildup at the crack locations. Figure 6(b) shows that the RT-1A coated specimen had a somewhat rougher surface appearance and less eruptions at crack locations than the HI-15 coated specimen. Figure 6(c) illustrates tight cracks in the Jocoated specimen and a very rough oxidized surface, consistent with the large weight gain that was observed. Of the three coatings tested the Jocoated WAZ-20 had the roughest surface appearance but the tightest cracks.

Metallography and microhardness. - Photomicrographs of transverse sections of WAZ-20 each coated with one of the three commercial coatings after 494 burner cycles are shown in figure 7. This figure illustrates the leading edge at two different magnifications. The better oxidation resistance of HI-15 coated specimens compared with RT-1A or Jocoated specimens is easily seen from this figure. Therefore, based on the weight change data and general freedom from oxidation in either the coating or substrate, the HI-15 coated WAZ-20 was ranked as best in oxidation resistance.

Since the HI-15 coated WAZ-20 was most oxidation resistant, it might have been expected that it would have better cracking resistance than it actually exhibited. But, as shown in the photomicrograph of HI-15 coated WAZ-20 after 182 test cycles (fig. 8), microcracks typically initiated at the coating interface and propagated through the gamma prime phase of the substrate. The reason for initiation at the coating interface and not at the surface can be determined by noting the difference in hardness between exposed and nonexposed sections of the test specimens.

A microhardness survey of the coated specimens was performed to determine the hardness at the interface areas. The results of a coating layer thickness and microhardness survey are given in table III. These data were obtained a few millimeters beyond the wedge surface, where oxidation was less severe for all specimens. From table III, it can be noted that the total coating thickness of each coating system increased. The cause is aluminum diffusion into the substrate. Because of the cyclic exposure, both the Jocoat and RT-1A coatings approximately doubled in thickness, and interface

hardness decreased. However, the HI-15 coating thickness increased by only about one-third, but interface hardness increased considerably. The KHN microhardness for the unexposed (see the section Metallographic Procedure) HI-15 coating interface was 690, but after 494 burner cycles it had increased to 960. By comparison, the Jocoat and RT-1A coating interface hardness decreased about 400 and 100 KHN, respectively. It appears that the change in hardness of the interface determines whether or not microcracks initiate and propagate into the substrate.

The propagation of a typical major crack in Jocoated WAZ-20 is shown in figure 9. This figure shows the macrocrack in the etched and unetched conditions after 494 burner cycles. The figure clearly shows that the macrocrack propagates along the dendritic structure in the WAZ-20 substrate. The cracks occur on boundaries oriented normal to the stress direction.

Fluidized-Bed Thermal Fatigue Study

Thermal cycling. - Thermal fatigue cracking results for both Jocoated random polycrystalline and Jocoated directionally solidified polycrystalline WAZ-20 alloy specimens were obtained from fluidized-bed testing. For the two Jocoated random polycrystalline specimens, the number of cycles to crack initiation were 100 and 138, the average initiation being at 119 cycles. For both Jocoated directionally solidified polycrystalline specimens, crack initiation was at 1750 cycles. These results show the typically consistent results obtainable from fluidized-bed testing. The thermal fatigue life of Jocoated WAZ-20 relative to a wide range of nickel- and cobalt-base superalloys is shown by the bar chart of figure 10 (ref. 6). For the cyclic conditions used, the cyclic life of the Jocoated random polycrystalline WAZ-20 ranked approximately in midrange of the cyclic lives previously obtained with most known nickel- and cobalt-base superalloys. Its cyclic life was approximately equal to that of NASA VI-A and René 80 alloys. Its thermal fatigue life was better than that of Jocoated MarM 200 but not as good as either Jocoated IN 100 or B 1900.

The directionally solidified polycrystalline form of Jocoated WAZ-20 had a thermal fatigue life about 14 times greater than that of the Jocoated random polycrystalline form. Although the cyclic life of the directionally solidified form of Jocoated WAZ-20 was the shortest of the five investigated directionally solidified alloys, it still was longer than those of all alloys evaluated in the random polycrystalline form.

Metallography. - Longitudinal sections were prepared after 700 fluidized-bed thermal cycles for the Jocoated random polycrystalline and 5500 cycles for the Jocoated directionally solidified polycrystalline WAZ-20 specimens. Photomicrographs of a major crack in each of the random and directionally solidified forms of WAZ-20 are

shown in figures 11 and 12. The photomicrograph of the Jocoated random polycrystalline WAZ-20 in figure 11 shows the same type of crack propagation as was observed in the burner tests (fig. 9); the cracks grew along the dendritic structure and were relatively tight. In the Jocoated directionally oriented alloy (fig. 12), coating cracks were sufficiently blunted by the substrate grain boundaries to retard crack growth. As the crack propagates into the specimen, it runs into a directional grain boundary and its growth is restricted or stopped. Also, the cracks are much wider in the directionally solidified alloy than in the random polycrystalline alloy. The cracks in the directionally solidified form appear rather like notches than cracks.

SUMMARY OF RESULTS

An investigation of the thermal fatigue resistance of coated NASA WAZ-20 was conducted in two stages - a burner screening study, and a fluidized-bed thermal fatigue study. Vendors applied coatings they selected as potentially suitable for the WAZ-20 alloy. The major results are as follows:

1. The screening study conducted in a Mach 1 natural-gas burner test facility indicated that Jocoated WAZ-20 had a cyclic life (cycled between 1065^o C and 340^o C) to macrocrack initiation 10 times that of RT-1A or HI-15 coated WAZ-20. However, of these three coating-substrate systems, the HI-15 coated WAZ-20 showed virtually no weight change and was best from an oxidation resistance standpoint.

2. The thermal fatigue life determined from fluidized-bed tests of Jocoated random polycrystalline WAZ-20 showed it ranked approximately in midrange of the lives previously obtained with a wide variety of nickel- and cobalt-base alloys. Its thermal fatigue life was longer than that of the Jocoated MarM 200 alloy, about equal to that of NASA VI-A and René 80 alloys, but shorter than those obtained for either Jocoated IN 100 or B 1900.

3. The fluidized-bed tests showed that the directionally solidified form of Jocoated WAZ-20 has a thermal fatigue life about 14 times greater than that of the Jocoated random polycrystalline form. The thermal fatigue life of directionally solidified WAZ-20 was shorter than that of other directionally solidified alloys but still longer than that of all alloys in the random form. In the directionally oriented material, coating cracks were sufficiently blunted by substrate grain boundaries to retard crack growth..

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, September 19, 1974,
505-01.

REFERENCES




1. Waters, William J.; and Freche, John C.: A Nickel Base Alloy, WAZ-20, with Improved Strength in the 2000^o to 2200^o F Range. NASA TN D-5352, 1969.
2. Howes, Maurice A. H.: Thermal Fatigue Data on 15 Nickel- and Cobalt-Base Alloys. IITRI-B6078-38, IIT Research Inst. (NASA CR-72738), 1970.
3. Moore, V. S.; Brentnall, W. D.; and Stetson, A. R.: Evaluation of Coatings for Cobalt and Nickel Base Superalloys, Volume 1. RDR-1474-2, Solar (NASA CR-72359), 1969.
4. Freche, John C.; Waters, William J.; and Ashbrook, Richard L.: Application of Directional Solidification to a NASA Nickel-Base Alloy (TAZ-8B). NASA TN D-4390, 1968.
5. Johnston, James R.; and Ashbrook, Richard L.: Oxidation and Thermal Fatigue Cracking of Nickel- and Cobalt-Base Alloys in a High Velocity Gas Stream. NASA TN D-5376, 1969.
6. Howes, Maurice A. H.: Additional Thermal Fatigue Data on Nickel- and Cobalt-Base Superalloys, Part 1. IITRI-B6107-34-Pt. 1, IIT Research Inst. (NASA CR-121211), 1973.

TABLE I. - ALLOY COMPOSITION

	Composition, wt. %				
	W	Al	Zr	C	Ni
WAZ-20 (nominal)	17 - 20	6 - 7	1.4 - 1.6	0.10 - 0.20	Balance
WAZ-20 alloy heat remelt stock ^a	19.90	6.28	1.49	0.17	Balance

^aAnalysis by independent testing laboratory.

TABLE II. - PHOTOMICROGRAPH DATA OF COATED WAZ-20 ALLOY SPECIMENS

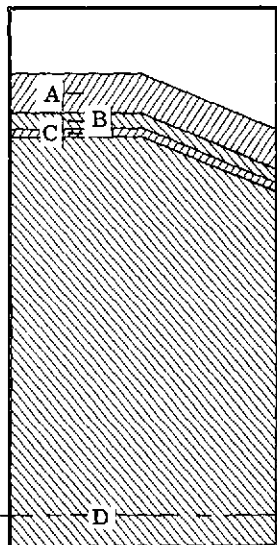
Figure	Test facility	Coating	WAZ-20 structure	Number of cycles ^a	Metallographic section		
					Preparation	Magnification	Orientation
7(a)	Burner ↓	HI-15	Random ↓	494 ↓	Etched ^b	10	Transverse 
7(b)		HI-15			↓	250	
7(c)		RT-1A			↓	10	
7(d)		RT-1A			↓	250	
7(e)		Jocoat			↓	10	
7(f)		Jocoat			↓	250	
8(a)	Burner ↓	HI-15	Random ↓	182	Unetched	250	Longitudinal 
8(b)		HI-15		182	Etched ^b	250	
9(a)		Jocoat		494	Unetched	35	
9(b)		Jocoat		494	Etched ^b	35	
11(a)	Fluidized bed ↓	Jocoat ↓	Random	700	Unetched	35 ↓	Longitudinal 
11(b)			Random	700	Etched ^b		
12(a)			Directional	5500	Unetched		
12(b)			Directional	5500	Etched ^b		

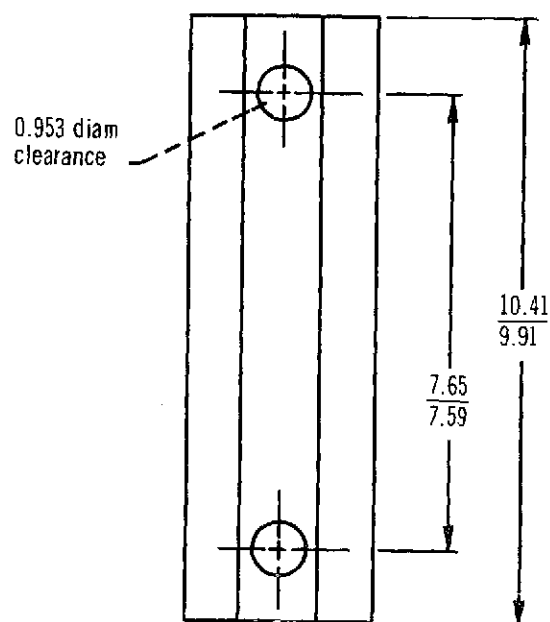
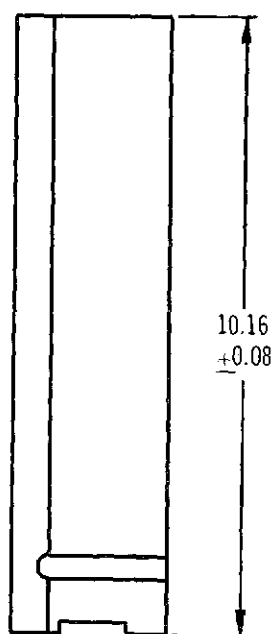
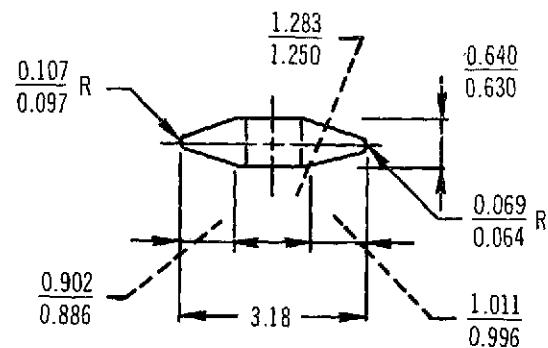
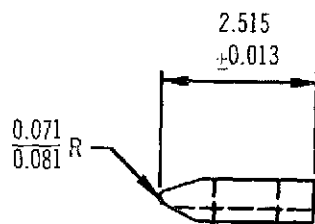
^aDescription of cycles: burner facility, 3 min to 1065° C and 30 sec to 340° C; fluidized-bed facility, 3 min to 1065° C and 3 min to 340° C.

^bEtchant: 33 parts nitric acid, 33 parts acetic acid, 33 parts water, and 1 part hydrofluoric acid.

TABLE III. - COATING THICKNESS AND MICROHARDNESS OF COATED WAZ-20 ALLOY SPECIMENS

Location	Thickness, μm		Microhardness ^a		Observations
	Unexposed	After 494 cycles	Unexposed	After 494 cycles	
RT-1A					
Coating outer layer (A)	10	30	455	515	Oxidized at 182 cycles
Coating inner layer (B)	25	30	490	575	Intact but not protective
Interface (C)	1	25	525	435	Oxidized at cracks and pits at 182 cycles
Centerline of substrate (D)	--	--	435	405	-----
Total	36	85			
HI-15					
Coating outer layer (A)	50	50	---	730	Outer layer spalled at pits in leading edge
Coating inner layer (B)	30	50	590	475	-----
Interface (C)	2	10	690	960	Protective except where thermal cracks propa- gate in substrate
Centerline of substrate (D)	--	---	465	550	-----
Total	82	110			
Jocoat					
Coating outer layer (A)	40	70	730	---	Pits in upper half of blade
Coating inner layer (B)	20	32	800	505	extend to substrate
Interface (C)	5	10	950	540	Broad microcracks (notches) in coating
Centerline of substrate (D)	--	---	420	425	-----
Total	65	112			

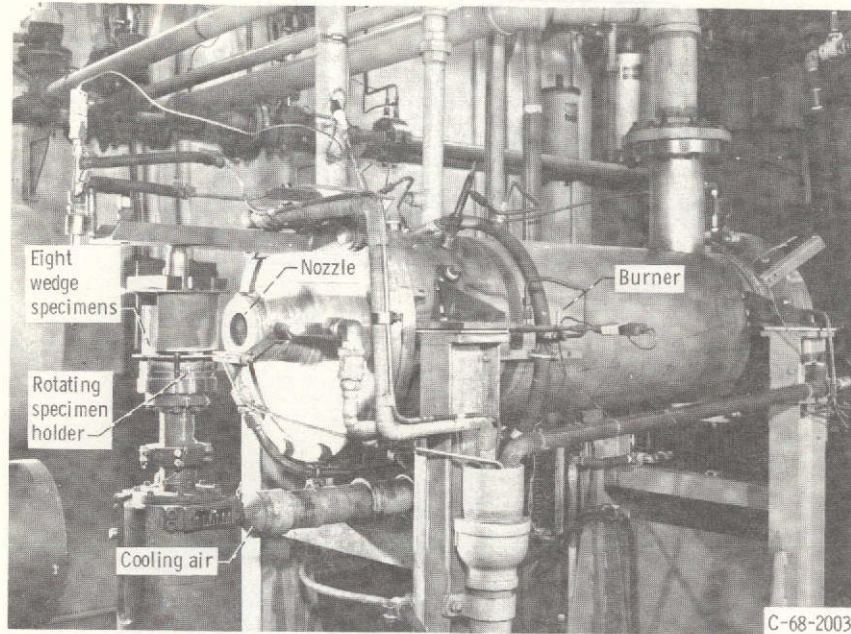
^aKHN using 50-g load.



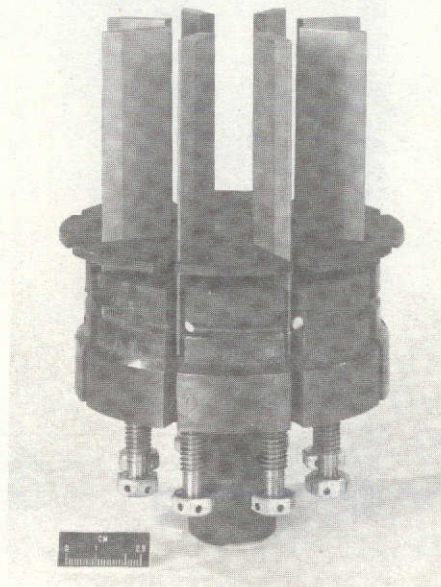
(a) Single-wedge specimen. (Used in burner facility.)

(b) Double-wedge specimen. (Used in fluidized-bed facility.)

Figure 1. - Geometry of test specimens. (All dimensions in centimeters.)

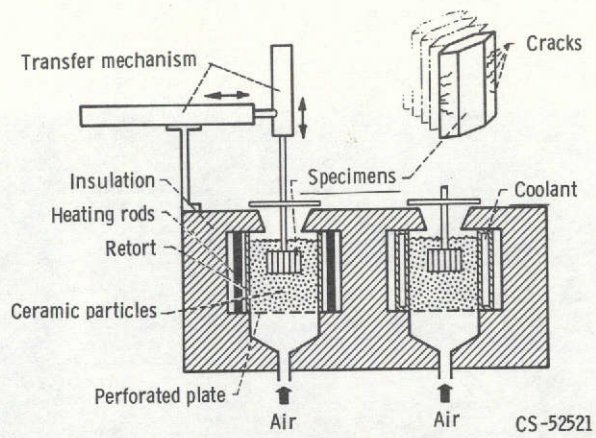


(a) General view of facility.

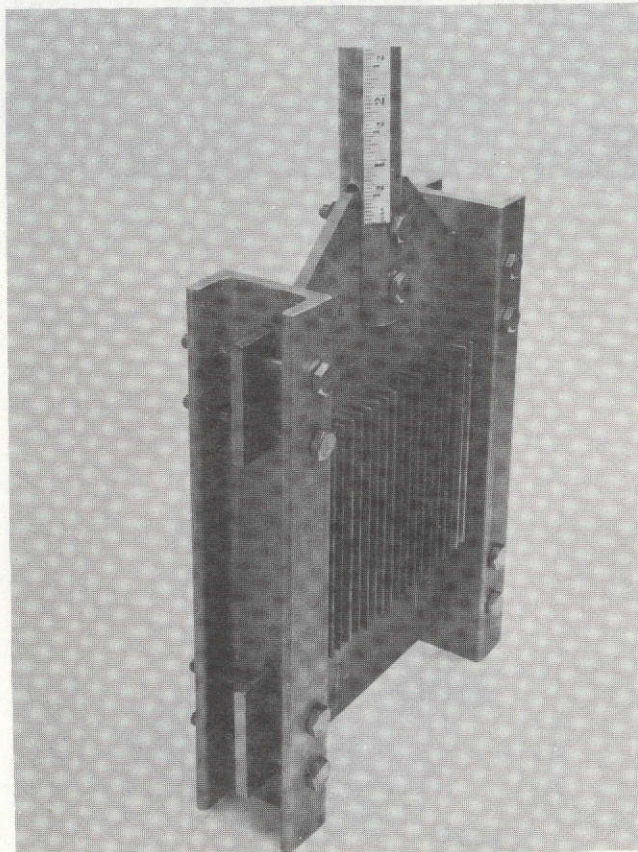


(b) Wedge specimens in holder.

Figure 2. - High-velocity open-jet burner facility.



(a) Schematic of test facility.



(b) Holding fixture with group of 18 specimens. (1 in. = 2.54 cm).

Figure 3. - Fluidized-bed test facility.

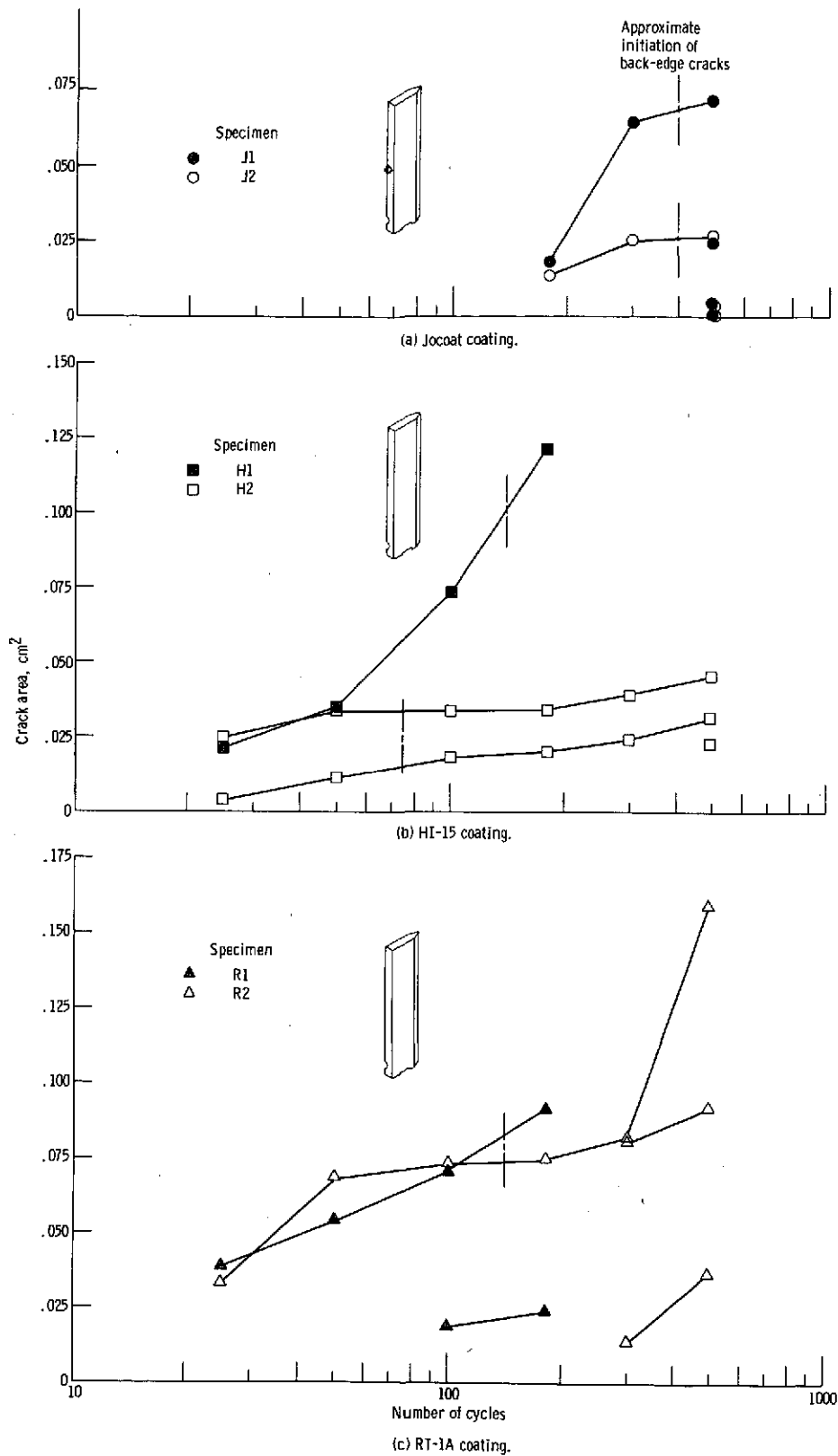


Figure 4. - Macrocrack data for coated WAZ-20 specimens tested in Mach 1 burner facility by cycling between 1065° C (3 min) and 340° C (30 sec).

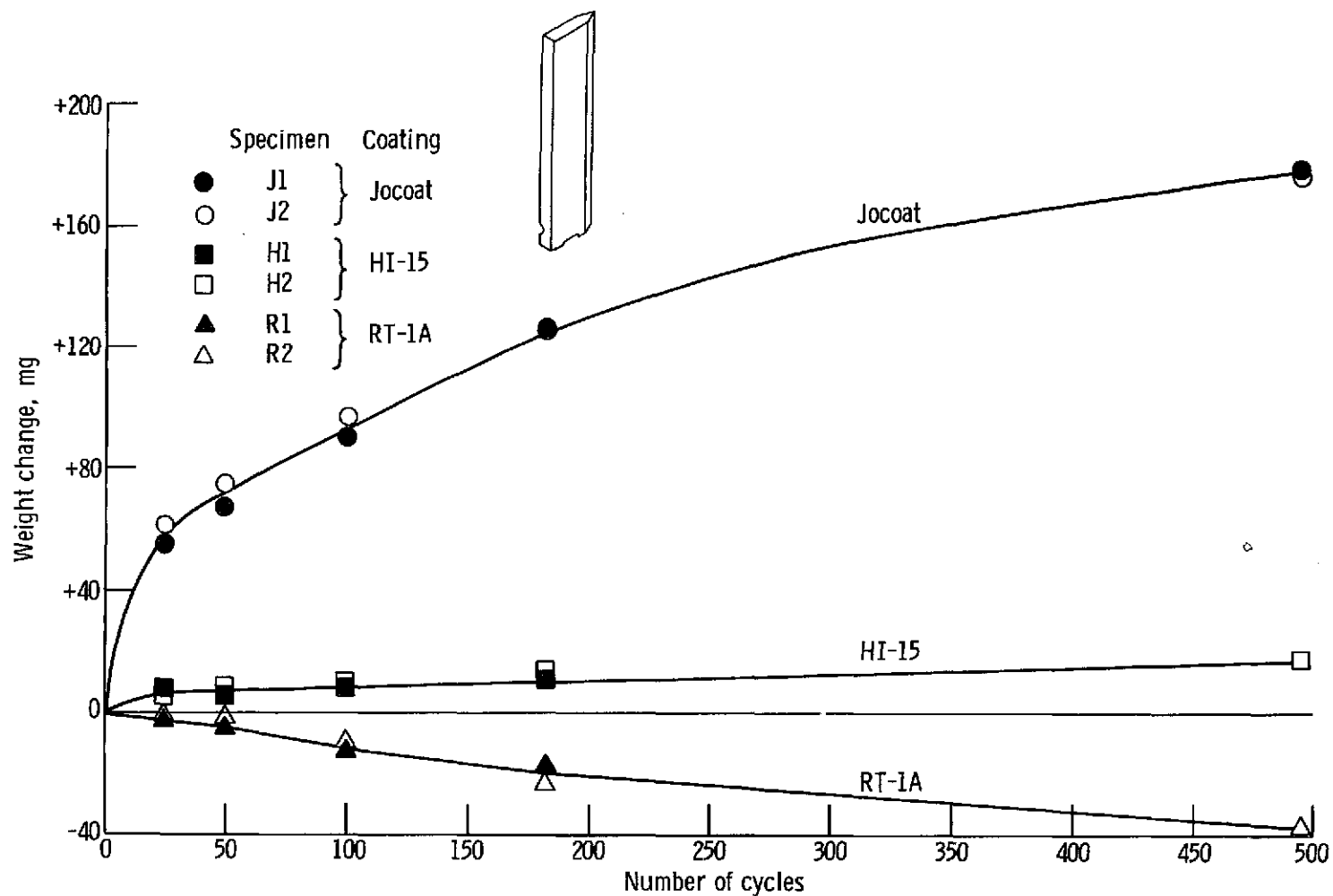
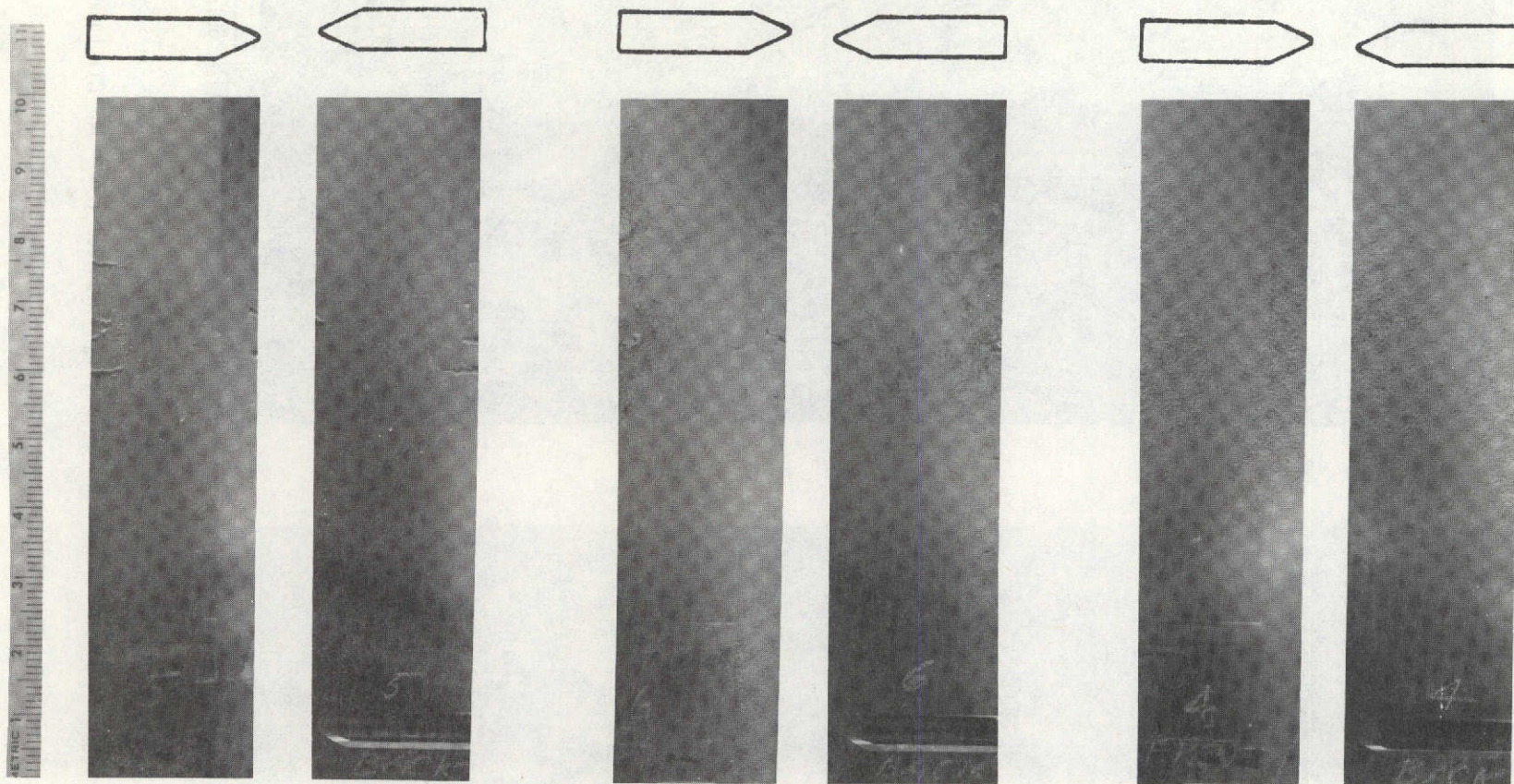


Figure 5. - Weight change data for coated WAZ-20 specimens tested in Mach 1 burner facility by cycling between 1065° C (3 min) and 340° C (30 sec).

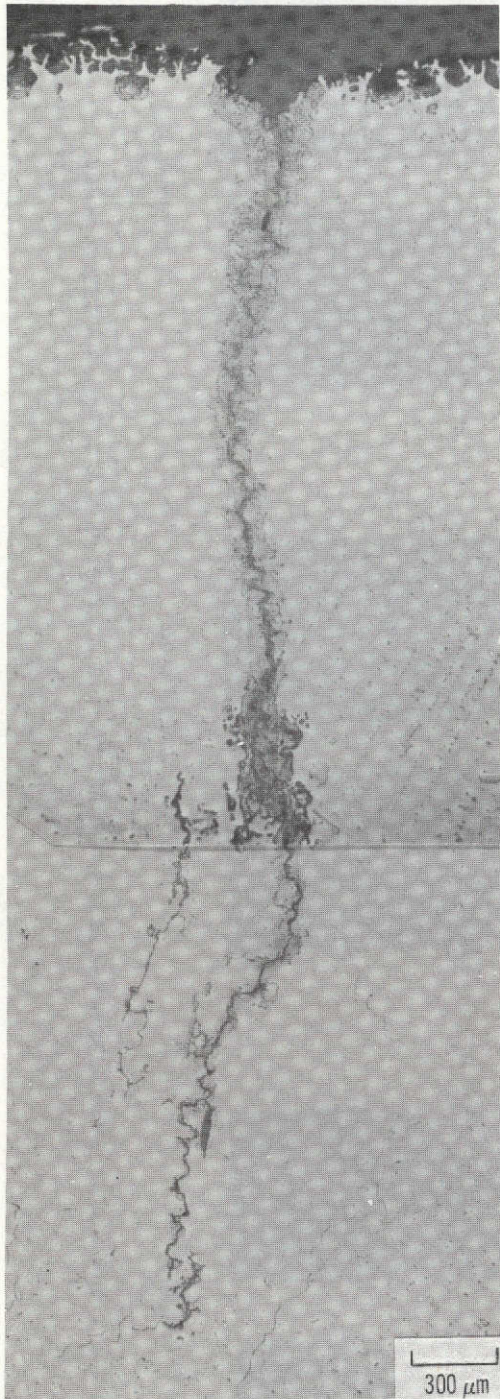


(a) HI-15 coated WAZ-20.

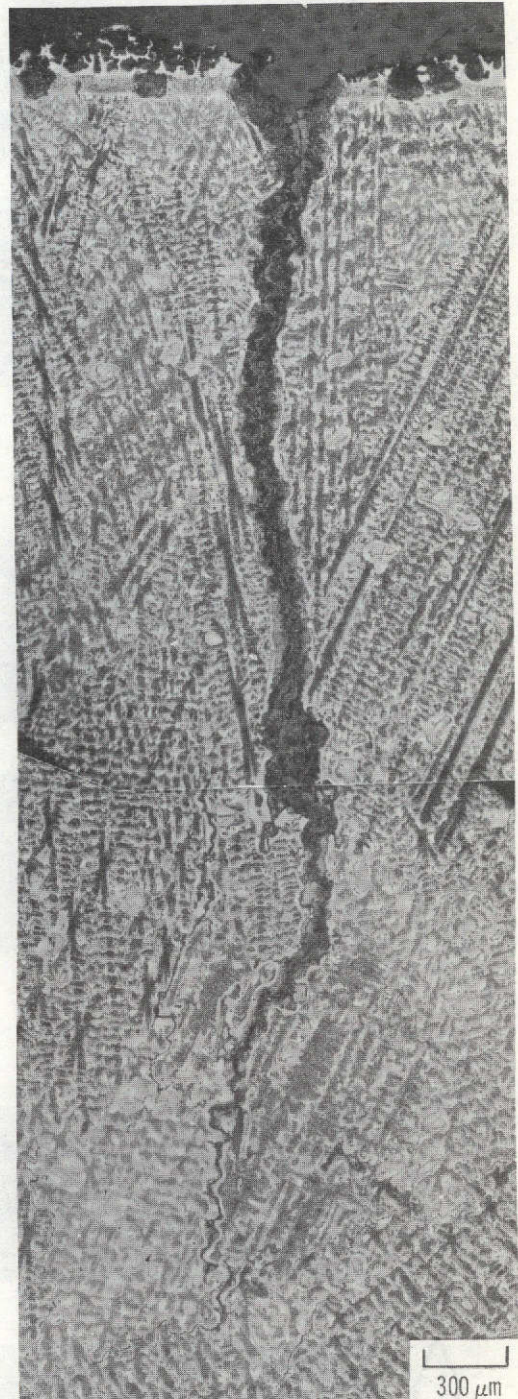
(b) RT-1A coated WAZ-20.

(c) Jocoated WAZ-20.

Figure 6. - Front and back surfaces of coated WAZ-20 specimens after 494 screening cycles ($1065^{\circ}\text{C} \rightleftharpoons 340^{\circ}\text{C}$) in burner facility.

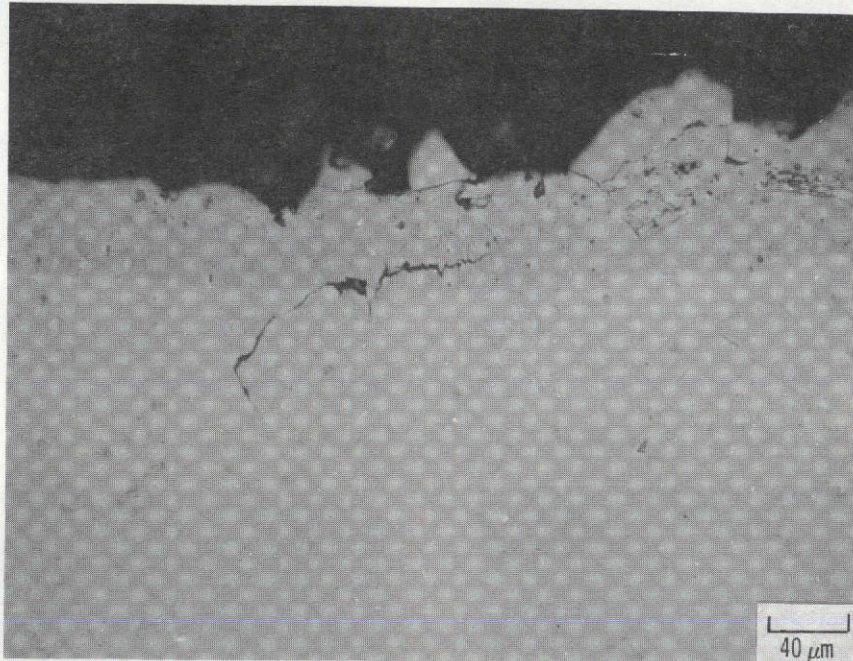


(a) Unetched.

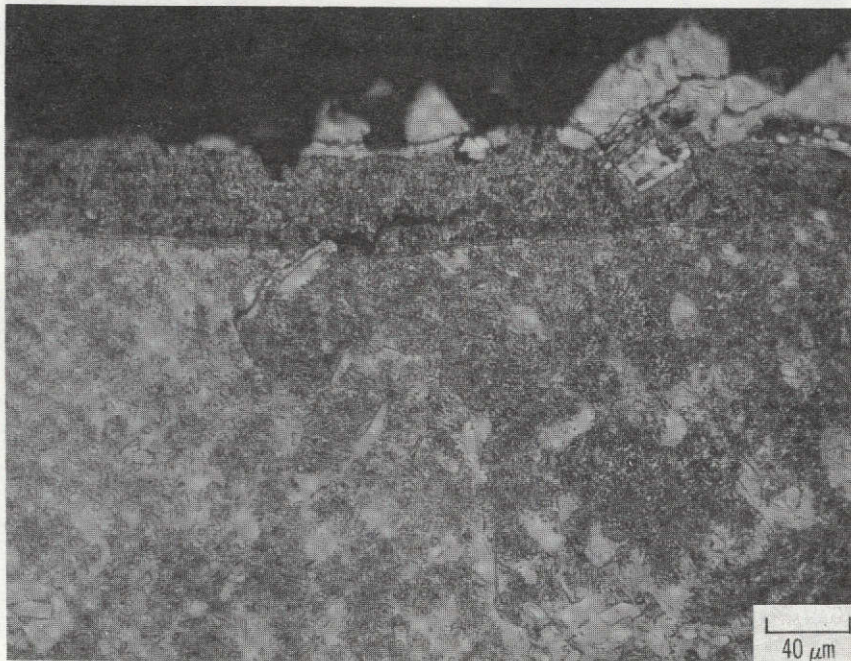


(b) Etched.

Figure 9. - Crack propagation of Jocoated WAZ-20 after 494 screening cycles ($1065^{\circ}\text{C} \rightleftharpoons 340^{\circ}\text{C}$) in burner facility. X35.

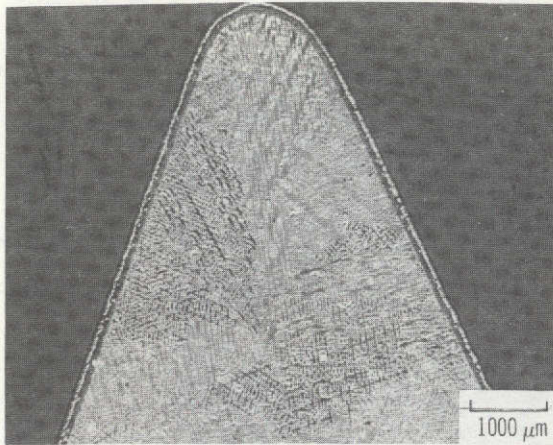


(a) Unetched.

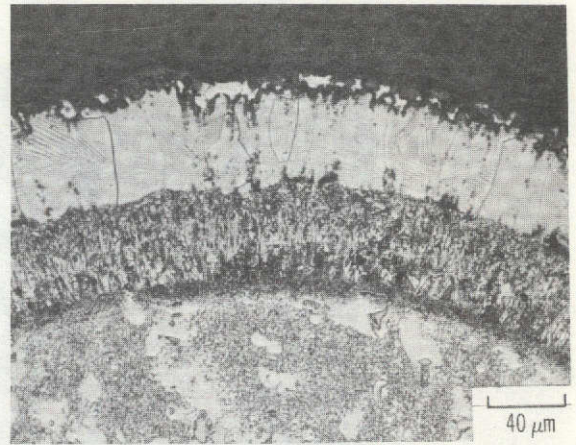


(b) Etched.

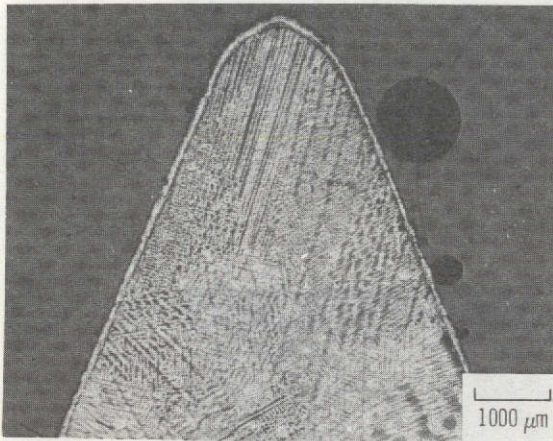
Figure 8. - Microcrack in HI-15 coating after 182 screening cycles ($1065^{\circ}\text{C} \rightleftharpoons 340^{\circ}\text{C}$) in burner facility. Longitudinal section; X250.



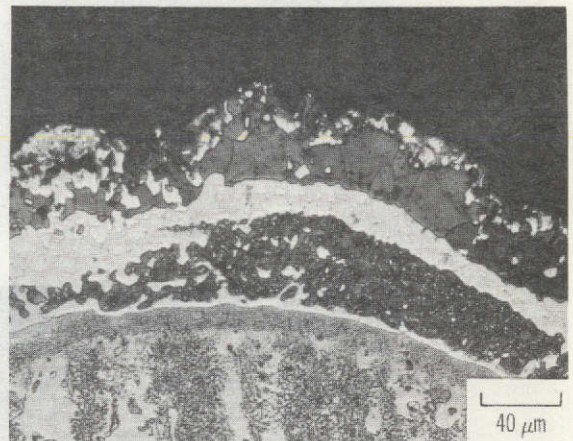
(a) HI-15. X10.



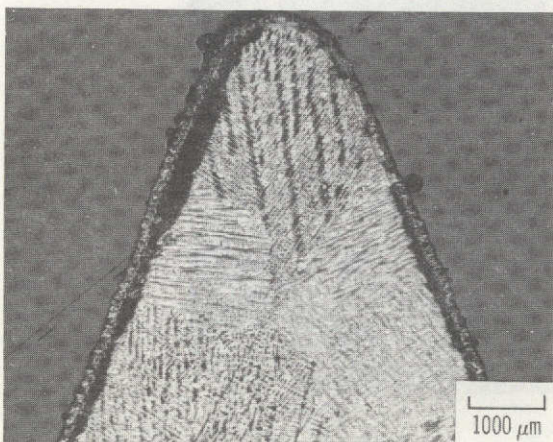
(b) HI-15. X250.



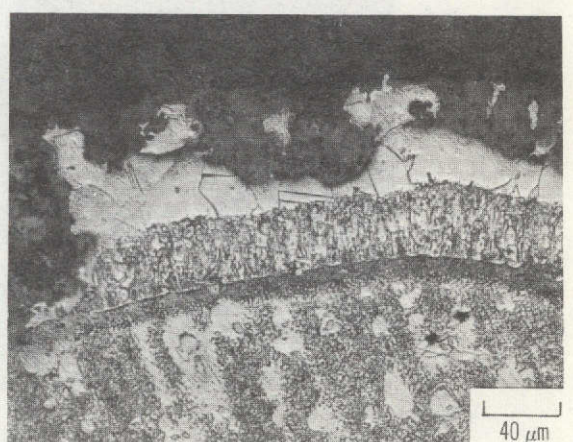
(c) RT-1A. X10.



(d) RT-1A. X250.



(e) Jocoat. X10.



(f) Jocoat. X250.

Figure 7. - Oxidation of coated WAZ-20 specimens after 494 screening cycles ($1065^{\circ}\text{C} \rightleftharpoons 340^{\circ}\text{C}$) in burner facility.

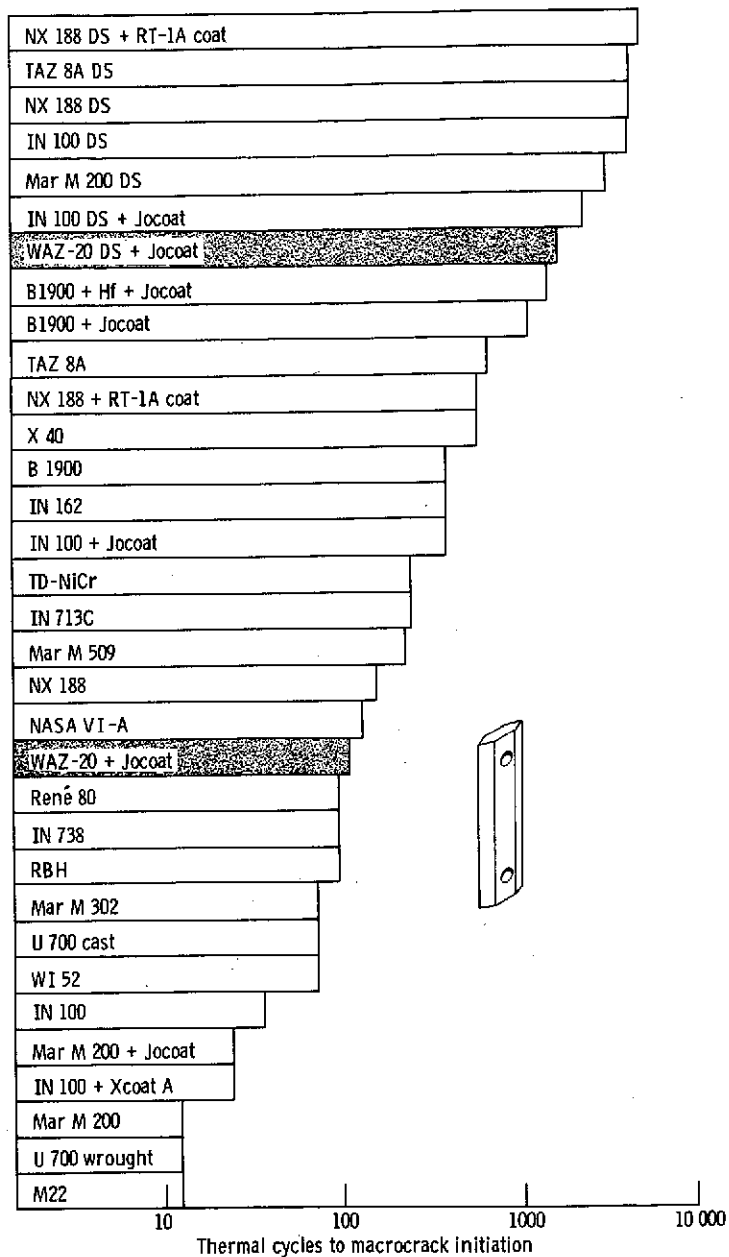
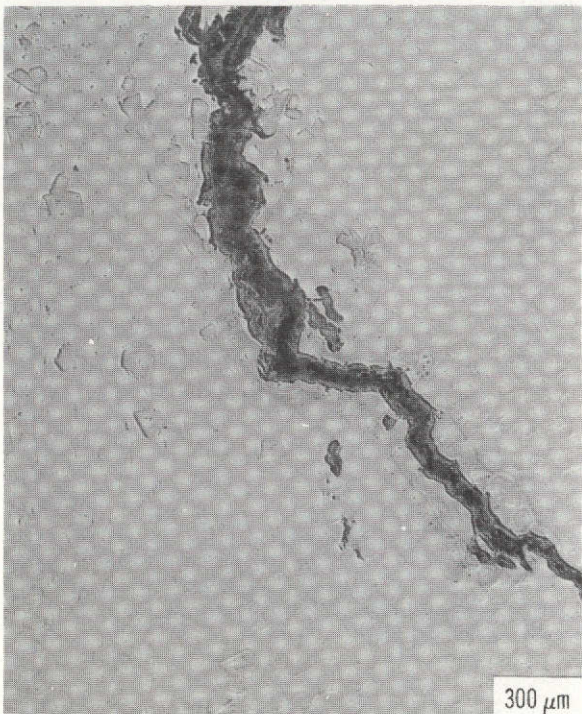
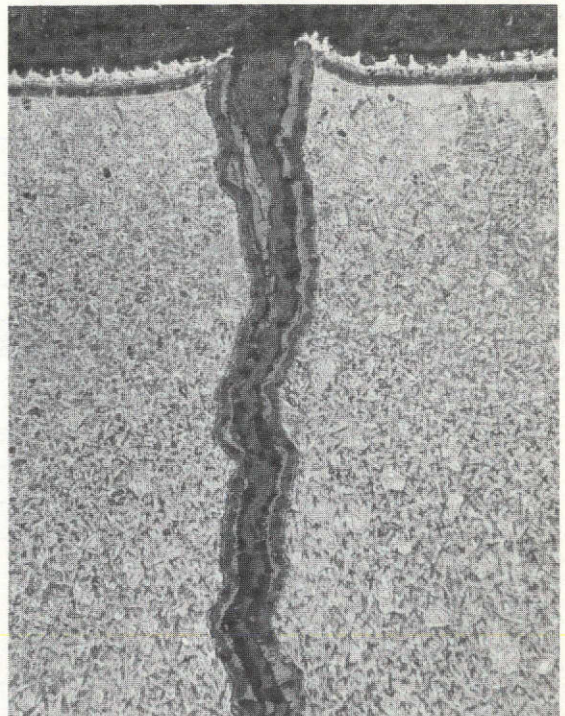
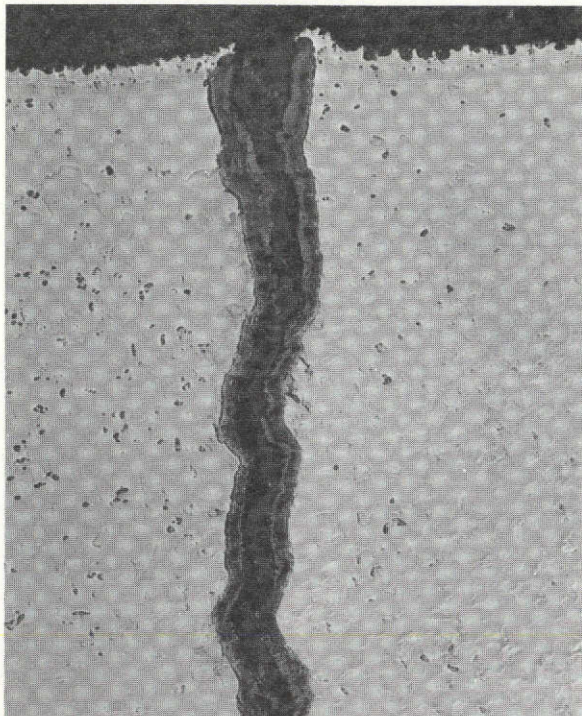


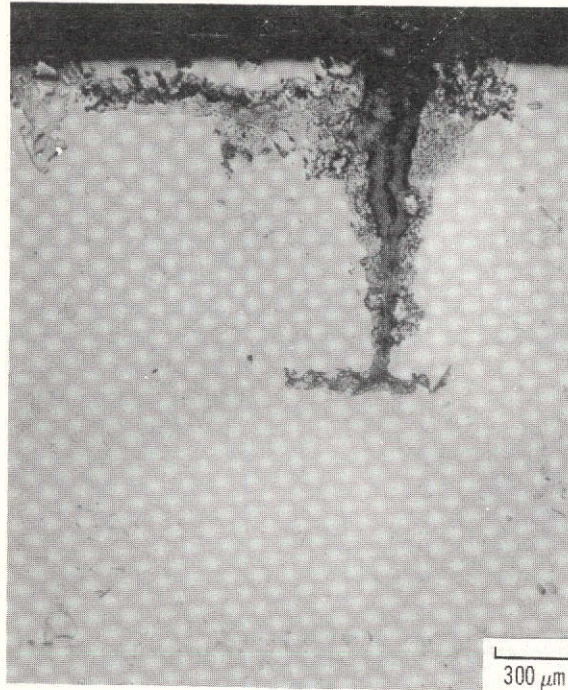
Figure 10. - Relative thermal fatigue resistance of superalloys tested in fluidized beds (ref. 6). 3 Minutes heating \pm 3 minutes cooling. WAZ-20 temperatures, $1065^{\circ}\text{C} \approx 340^{\circ}\text{C}$.



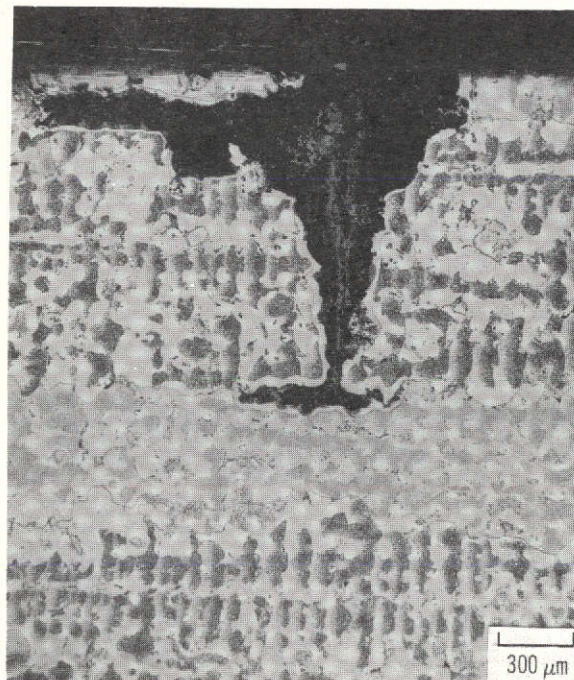
(a) Unetched.

(b) Etched.

Figure 11. - Crack in located random polycrystalline WAZ-20 after 700 thermal fatigue cycles ($1065^{\circ}\text{C} \rightleftharpoons 340^{\circ}\text{C}$) in fluidized bed facility. Longitudinal section; X35.



(a) Unetched.



(b) Etched.

Figure 12. - Blunted crack in Jocoated directionally solidified polycrystalline WAZ-20 after 5500 thermal fatigue cycles ($1065^{\circ}\text{C} \rightleftharpoons 340^{\circ}\text{C}$) in fluidized-bed facility. Longitudinal section; X35.